Gamma-Ray Bursts as a Tool for Cosmology

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Gamma-ray bursts are brief, intense, and complex flashes of gamma-ray energy that emanate from seemingly random point-like locations on the sky at unpredictable times. Until recently, the accepted theory of the origin of bursts involved the production of gamma-ray energy in or near the powerful magnetic fields of neutron stars. The launch of the Burst and Transient Source Experiment, with its ability to localize each detected burst to a restricted region of the sky, was expected to produce a map of the positions of these bursts, revealing the band of the Milky Way.

Contrary to expected results, however, the ensemble of positions for over 1,100 bursts detected to date is isotropic (fig. 14 of preceding article). The burst experiment has also shown that the radial distribution of bursts is inhomogeneous: beyond some unknown distance, the number density of burst sources decreases below the value observed locally in space. This behavior is signaled by the comparative deficit of faint bursts in the data, displayed graphically by the failure of the brightness distribution to continue along the indicated –3/2 line (indicative of homogeneity), instead falling far below the line at low brightnesses (fig. 15 of the preceding article). We appear to be at the center of a confined, spherical distribution of burst sources—a situation found in observing no other set of galactic objects.

Most scientists now believe that this combination of angular isotropy and spatial inhomogeneity is explained by a population of bursts not in our own galaxy, but at cosmological distances near the edge of the observable Universe. The isotropy of the bursts in this model is a natural consequence of the Universe looking the same in all directions on large scales. The deviation of the brightness distribution from the –3/2 line is caused by cosmological effects related to the known expansion of the Universe, specifically red-shifting of the burst spectrum and time-dilation of both the apparent rate of photon emission and the time between burst events. If the cosmological model is correct, the bursts' tremendous distances require them to be among the most energetic objects in the Universe, releasing in just 10 seconds perhaps as much energy as the Sun emits in its total lifetime.

Bursts at cosmological distances not only offer the possibility of serving as interesting physics laboratories in their own right, but may help us learn how the Universe is put together. The manner in which the brightness distribution deviates from the –3/2 line in the cosmological burst scenario is, in part, dependent on the values of two important cosmological numbers: σ_o, the "density parameter," which describes how much material is contained in the Universe, and q_o, the "deceleration parameter," which describes how fast the expansion rate of the Universe is changing with time.

The numerical values for these parameters are unknown, yet they have already determined the eventual fate of the Universe. Will the Universe continue to expand forever? Will the Universe eventually stop expanding, begin to contract, and eventually end with a "big crunch?" What is the geometry of the Universe, "open" or "closed?" Each of these questions could be answered precisely, provided one had a reliable, accurate measure of the values of σ_o and q_o.

In addition to the values of σ_o and q_o, the shape of the burst-brightness distribution also depends on how far out into the Universe researchers can detect bursts, the relative frequency and energy output of bursts in the early Universe compared to today, and the exact shape of the gamma-ray bursts' individual spectra. Each of these can be measured or estimated to varying degrees of uncertainty.

By comparing the shape of the observed brightness distribution to that of a model distribution that incorporates specific values of σ_o, q_o, and other parameters, researchers can assess the consistency between a given model of the Universe and the observed gamma-ray burst distribution. In this way, one can learn what possible constructions of the Universe may be valid and, equally important, what ones may be invalid. Further information can be obtained by combining results with independent measurements of other cosmological objects using such experiments as the Hubble Space Telescope.

Indeed, the use of gamma-ray bursts as a tool in cosmology is an illustration of the serendipitous nature of the scientific enterprise. The Burst and Transient Source Experiment was built to confirm the belief that bursts were mildly energetic releases of energy occurring in our own Milky Way Galaxy. Instead, the experiment has revealed the possibility that bursts are among the most distant and energetic objects in the cosmos. As such, they offer the possibility of serving as an excellent new tool to explore the structure, dynamics, and eventual fate of the Universe.

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